

# Parametric Study on Diagrid Structural System with and without Shear Walls

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**Abstract**— Among the various lateral load resisting systems of the tall structures, diagrid structural system is a unique structural system and found effective compared to other bracing systems, which is increasingly popular from the past decades. The diagrids are perimeter structural configurations characterized by a grid of diagonal members which are involved both in gravity and in lateral load resistance. The diagrid structure ensures the overall stiffness and strength of the building only engaging the diagonal members in a purely axial behaviour and fully braces the interior gravity columns for stability only at joints of diagrid. The intermediate floors, are not laterally restrained by the global behaviour of the diagrid system, means if diagonals are continuous throughout the module height, the floors would derive a certain degree of lateral stiffness only from the flexural stiffness of the diagrids. Although diagrid system is good enough to perform well in lateral load resisting compare to other simple frame and shear wall building, we can combined the diagrid structure with shear walls for optimum design. The present study aimed to understand the behaviour of the diagrid structural system with shear walls at core. For this study a regular square plan of 30m × 30m diagrid structure considering different storey module (i.e. 4, 6, 8 & 12) with and without core Shear Walls is modelled and analyzed. For minimum displacement and drift different plan shape of shear wall are taken and one of them with optimum results is used for further analysis. Then behaviour of diagrid structure with and without shear wall along the height is also studied considering 24, 36 and 48 storey. ETABS software is used for modelling and analysis. Parameters such as inter storey drift-ratio, storey displacement, base shear and reduction in lateral load on diagrid are taken into consideration.

**Keywords**— Diagrid structure, Inter storey drift ratio, Shear wall, Storey module, Storey displacement, Tall building.

## I. INTRODUCTION

The lateral loading due to wind and earthquake is governing factor that causes the design of high-rise buildings. These lateral loads are resisted structural by different structural system provided. The lateral load resisting systems that are used mainly shear wall, wall-frame, braced tube system, outrigger system, diagrid system and tubular system.

Diagrid is an exterior structural system in which all perimeter vertical columns are removed and replaced by inclined columns on which is called diagrids. Shear and over-turning moment developed due to lateral loads are resisted by axial action of these diagonals. As most diagrid structures have core as partial lateral stability. The diagrid structure is an extension of the tube-in-tube structure,

where the outer tube is comprised of diagrids. There is bit confusion between the conventional exterior braced frame structure and diagrid structure but the major difference between them is that in a diagrid structure, peripheral columns are eliminated. This is because in diagrid structures, diagrids are also takes the gravity load in addition to the lateral load by triangulated configuration, while the conventional bracing system could not take any gravity load.[14]

Structural systems of tall buildings can be divided into two broad categories: core structures and exterior/peripheral structures, which is based on the distribution of the components of the primary lateral load-resisting system over the building. A system is categorized as an core structure when the major part of the lateral load resisting system is located at core of the structure. Similarly, if the

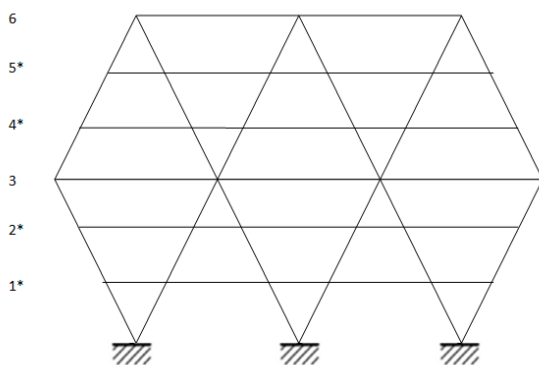
major part of the lateral load-resisting system is located at the perimeter of structure, a system is called as an exterior structure.[11]

The major types of lateral load-resisting systems in category of core structures are the moment-resisting frames and shear walls. These systems are usually arranged as planar assemblies in two principal orthogonal directions and may be used as a combined system. The building perimeters has more structural significance in tall buildings due to their very tallness, which means greater vulnerability to lateral forces, especially wind loads. Therefore, it is quite desirable to concentrate as much lateral load-resisting system components as possible on the perimeter of tall buildings to increase their structural depth, and, in turn, their resistance to lateral loads.[11]

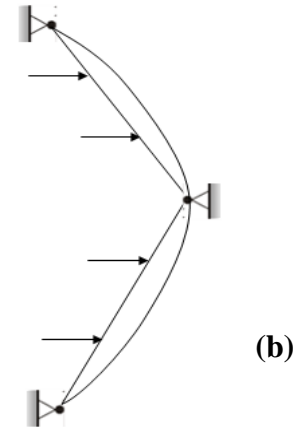
The design of the modules comes first among the items to be decided while planning the diagrid structure. The criteria for design of the modules are the suitability of the gap angle, topographic conditions, strength, height of the structure, loads, etc. How many floors there will be between node numbers of each modules, the angle and dimensions of the structural tubes vary as per requirements of design.[12]

### 1.1 Drawbacks (Local issue) of Diagrid Structural System

The structural behaviour of systems with mega-diagonals could be assimilated to a vertical truss with panel points (diagrid nodes) located multiple floors apart in Fig.1.1(a)[7] is sketched a typical diagrid system. The diagrid structure ensures the global stiffness and strength of the overall building by considering diagonal members as truss member in design (purely axial behaviour) and braces the interior gravity columns for stability only at panel points. The intermediate floors in Fig. 1.1(a)[7], are not laterally restrained by the global behaviour of the diagrid system; in other words, if diagonals are continuous throughout the module height, the floors would derive a certain degree of lateral stiffness only from the flexural stiffness of the diagonals Fig. 1.1(b).[7]



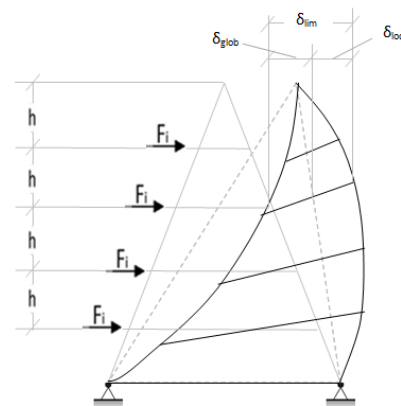
(a)



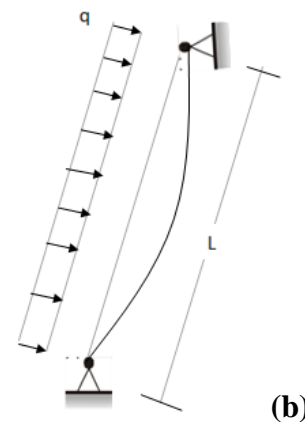
(b)

Fig. 1: (a) Typical diagrid system (b) Mega-diagonal elements between panel points.[7]

Within given the module height, the diagrid members provide a partial lateral restraint with the help of their flexural stiffness. This partial restraining could be or not sufficient to brace the internal columns, activating a single floor buckling mode, and to limit inter storey drifts.[7]



(a)



(b)

Fig. 2: (a) Lateral deformation of diagrid module (b) The diagrid diagonals under horizontal forces.[7]

## II. METHODOLOGY

First step is to find optimum plan shape/placement of shear wall at core, for which parameters such as displacement and inter- drift ratio is taken into consideration. For this RC bare frame structure with four different placement/plan shape shear walls at core is taken and analysis is carried out and lateral loads (Seismic and Wind) are considered.

After analysis, one case with optimum/minimum displacement and inter- drift ratio will taken into consideration for further analysis for diagrid structure with and without shear walls.

In second part of work diagrid structure with four different module (i.e. 4, 6, 8, 12 module ; Angle of diagrid  $\theta = 67.38^\circ, 74.47^\circ, 78.23^\circ, 82.09^\circ$  respectively) taken into consideration with and without shear walls at core of structure. Each case is also analyzed with three different height (i.e. 24, 36 and 48).

Square RC framed structure with steel pipe section diagrids at periphery is considered for modeling. Lateral loads are seismic and winds are taken into consideration as per Indian Standard codes IS 1893 (Part 1) : 2016 and IS 875 (Part 3) : 2015 respectively.

### 2.1 Placement/Plan-Shape of Shear Wall At Core

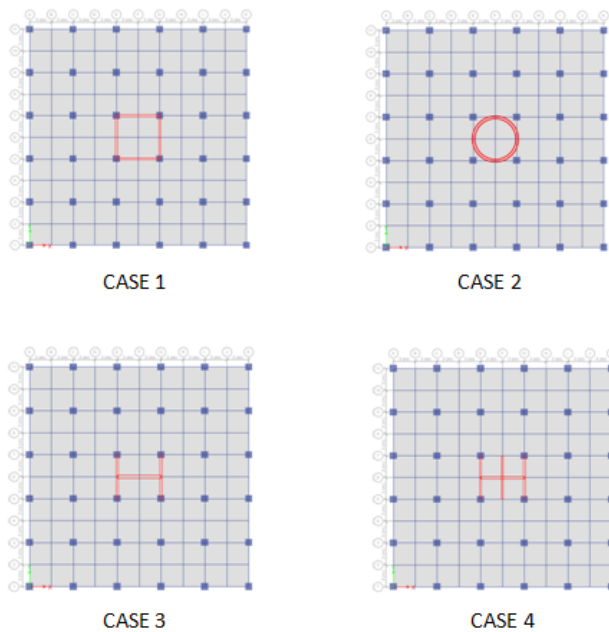


Fig. 3: Shear Walls at core (a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4

### 2.2 Diagrid Structure with and Without Shear Walls

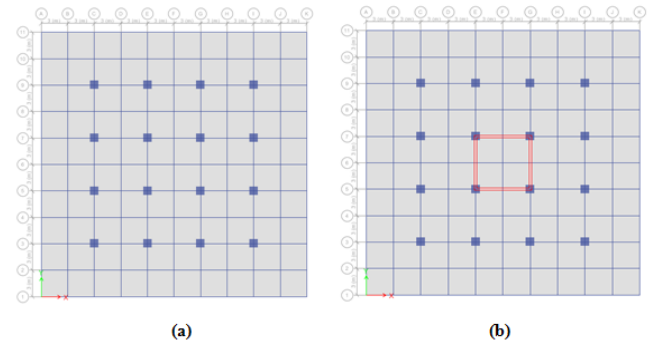


Fig.4 : Plan of Building (a) without shear wall (b) with shear wall

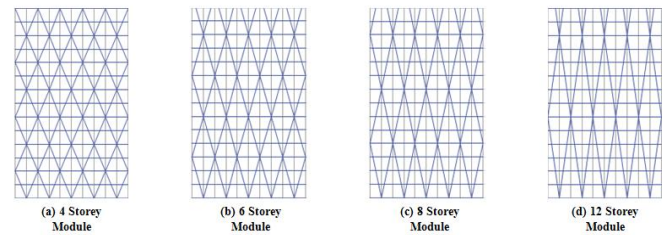


Fig.5: 4, 6, 8 and 12 storey diagrid Module

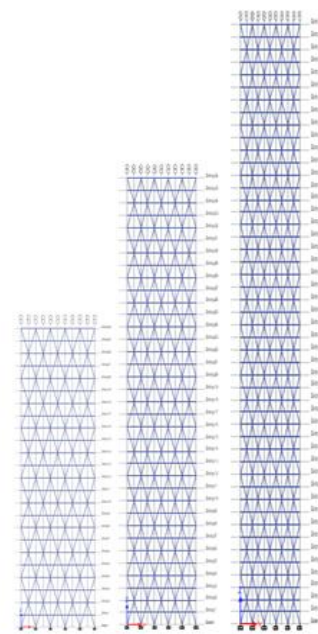


Fig. 6: 4 Module : 24, 36, 48 Storey

## III. GEOMETRIC DATA

Table 1: Model Details

PLAN	30m × 30m	
HEIGHT	3.6m	
MEMBER SIZE	BEAM	300mm X 500mm
	SLAB	120mm

	SHEAR WALL	250mm
MATERIAL TYPE	CONCRETE	BEAM-M30
		COLUMN-M40
		SLAB-M30
		SHEAR WALL-M30
	STEEL	REBAR-HYSD 500
		DIAGRID-Fe345
LOAD	DEAD(FF)	1.0 KN/m <sup>2</sup>
	LIVE	3.0 KN /m <sup>2</sup>
MATERIAL DENSITY	CONCRETE	25kN/m <sup>3</sup>
	STEEL	78.5kN/m <sup>3</sup>
SOIL TYPE	MEDIUM OR STIFF SOILS	
RESPONSE REDUCTION FACTOR (R)	5	
IMPORTANCE FACTOR (I)	1.2	
ZONE	III	
BASIC WIND SPEED	39 m/s	
TERRAIN CATEGORY	III	

Table 2 : Column section details for 24, 36, 48 storey height

STOREY	SECTION SIZE
24	950mm X 950mm
36	1150mm X 1150mm
48	1350mm X 1350mm

Table 3 :Diagrid (Diagonal) pipe section details

STOREY	MODULE	SECTION SIZE (OUTER DIAMETER-THICKNESS)
24	4	350 mm - 15mm
	6	400 mm - 20mm
	8	450 mm - 25mm
	12	550 mm - 30mm
36	4	350 mm - 25mm

	6	420 mm - 25mm
	8	500 mm - 25mm
	12	620 mm - 30mm
48	4	370 mm - 30mm
	6	450 mm - 30mm
	8	550 mm - 40mm
	12	650 mm - 40mm

Table 4 : Nomenclature for cases considered

STOREY/MODULE	4	6	8	12
24	A1	A2	A3	A4
36	B1	B2	B3	B4
48	C1	C2	C3	C4

## IV. RESULT AND DISCUSSION

### 4.1 Placement/Plan-Shape Of Shear Wall At Core

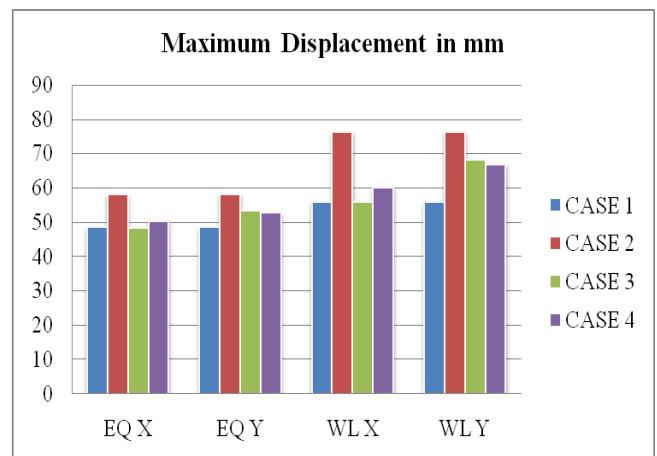


Fig. 7: Maximum Story Displacement in mm

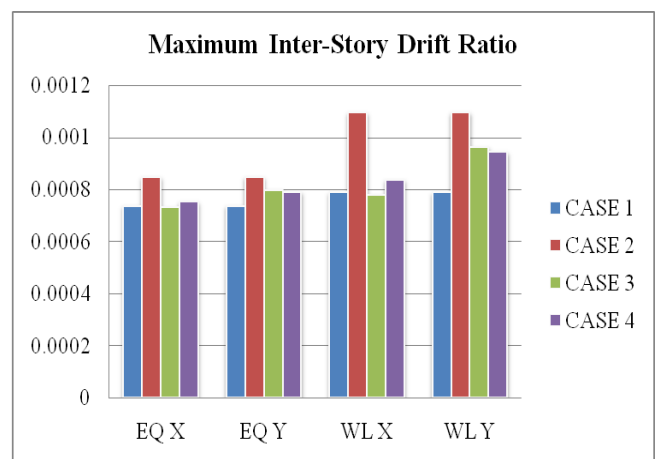


Fig. 8: Maximum Inter-Story Drift Ratio

Results and plot of displacement and inter-storey drift ratio are showing that Case 1 which is square box type placement of shear wall at core is having minimum displacement and inter drift ratio in both directions and also in seismic and wind loads. Therefore shear wall of Case 1 (square) will be used for diagrid structure modeling with shear walls at core for optimum results.

## 4.2 Diagrid Structure With And Without Shear Walls

### 4.2.1 Maximum Displacement Results

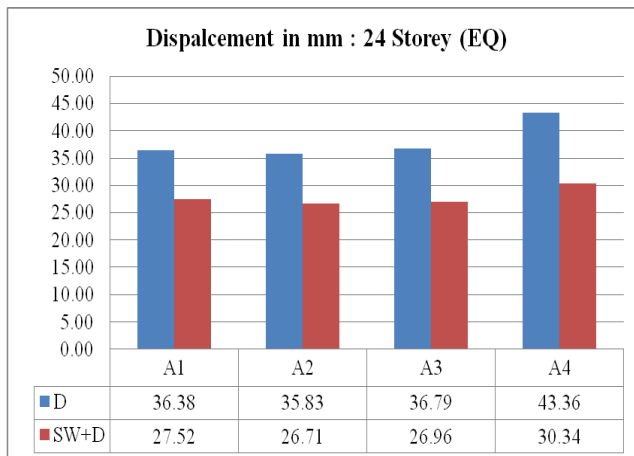


Fig. 9: Maximum Story Displacement in mm 24 Storey

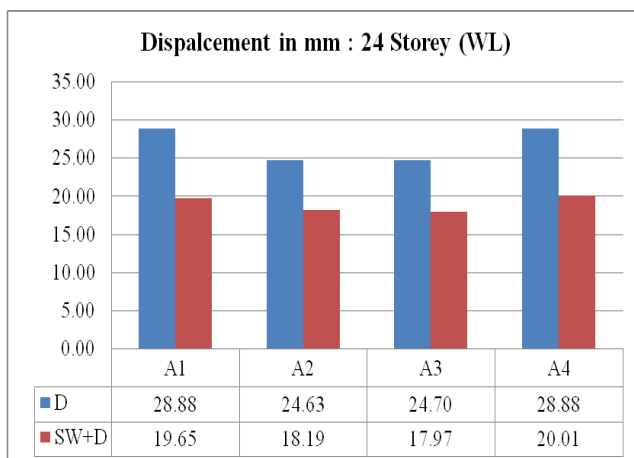


Fig. 10: Maximum Story Displacement in mm 24 Storey

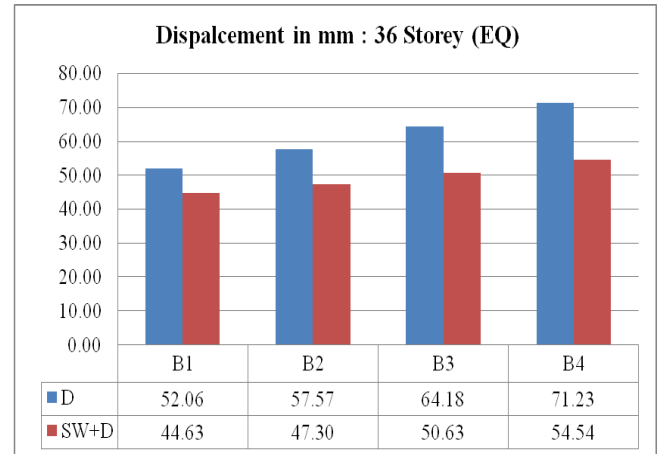


Fig. 11: Maximum Story Displacement in mm 36 Storey

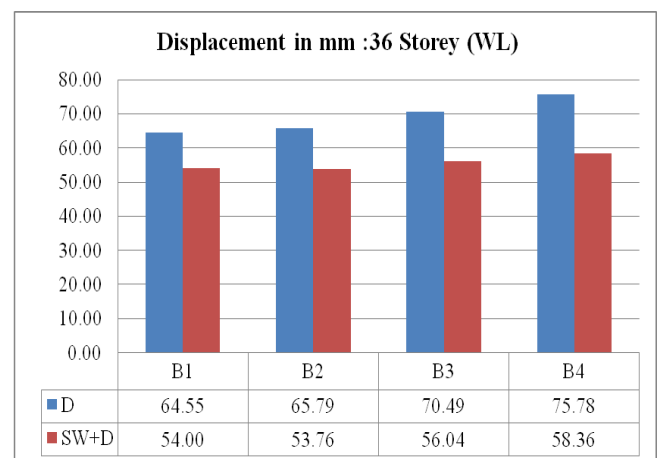


Fig. 12: Maximum Story Displacement in mm 36 Storey

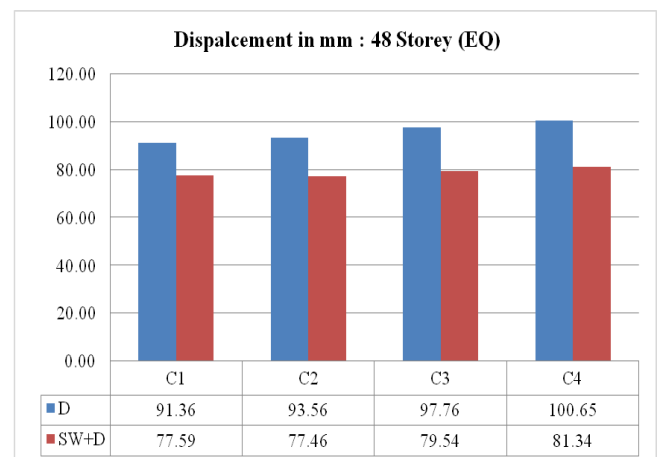


Fig. 13: Maximum Story Displacement in mm 48 Storey

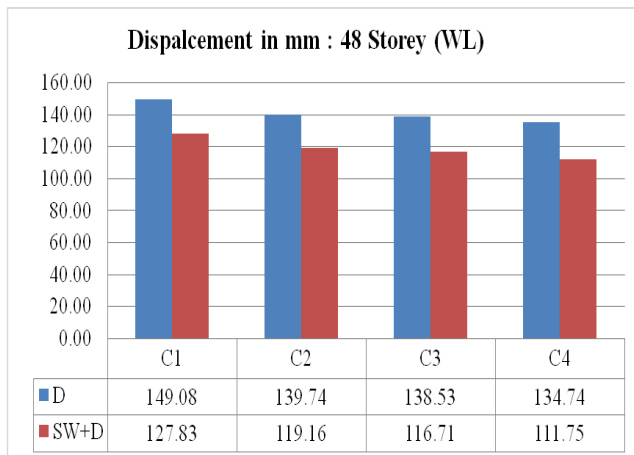


Fig. 14: Maximum Story Displacement in mm 48 Storey

#### 4.2.2 Inter Drift Ratio Results

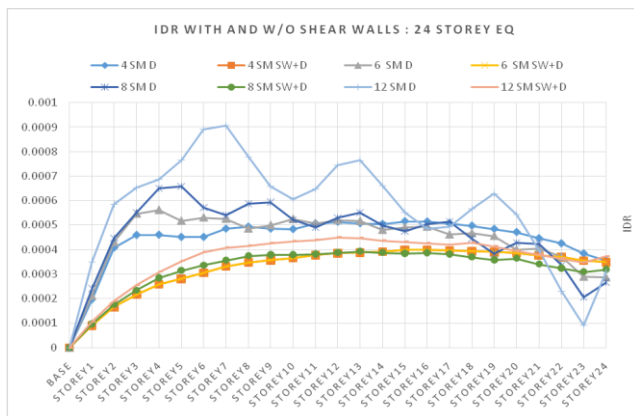


Fig. 15: Inter storey drift ratio : 24 storey (EQ)

As mentioned above within the diagrid storey module intermediate floors are partially restrained and having less storey stiffness which results in high inter storey drift ratio, but after providing shear wall at core, that increases the stiffness and imparts the lateral stability with help of their large in plane stiffness. From results it is clear that in almost all the cases of diagrid structure, major issue is of excessive inter storey drift ratio, which is eliminated with help of shear walls at core.

#### 4.2.3 Percentage Reduction In Maximum Inter Drift Ratio

Table 4: Reduction in maximum IDR(%)

EQ			
	24 Storey	36 Storey	48 Storey
4 Module	22.52	13.41	13.83
6 Module	29.00	16.91	15.71
8 Module	40.43	24.03	17.72
12 Module	50.33	37.43	21.98
WL			
	24 Storey	36 Storey	48 Storey
4 Module	53.18	13.81	12.65
6 Module	35.41	17.30	12.43
8 Module	42.57	26.27	14.66
12 Module	49.74	37.07	24.93

It is found that shear walls at core in diagrid structure will almost eliminate the local stability and flexibility issue within the diagrid module. This happens because when shear walls are provided at core due to their large in plane stiffness they increase the stiffness of overall diagrid structure and not only at node points.

From result and plot of percentage reduction in maximum inter drift ratio it is found that decrement in inter drift with increase in module, increases significantly and in steep angle diagrid building it is giving maximum reduction.

#### 4.2.4 Reduction In Reaction On Diagrid

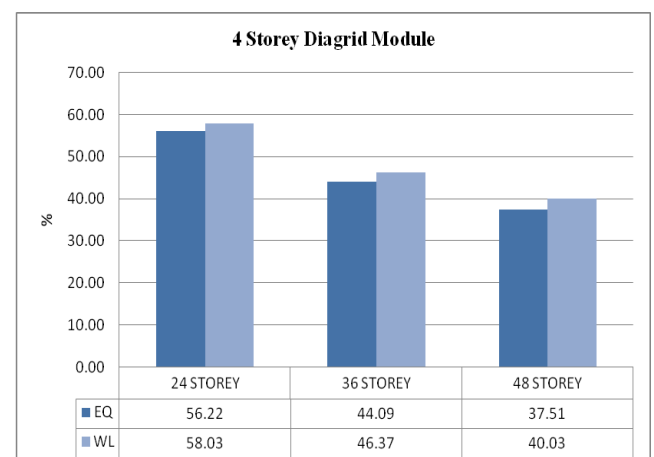


Fig. 16: 4 Story diagrid module



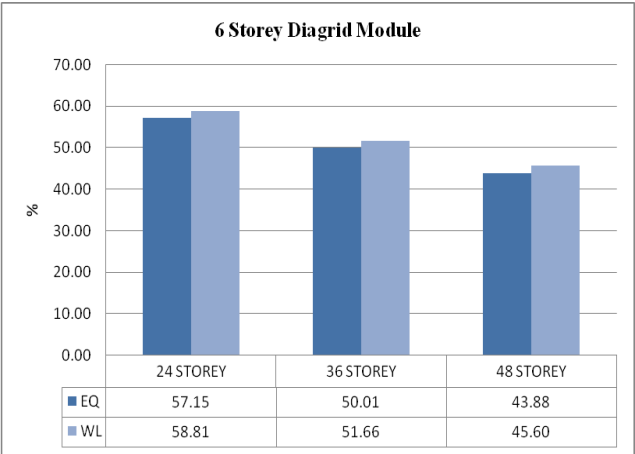


Fig. 17: 6 Story diagrid module

4.2.5 Base Shear With & Without Shear Wall under EQ

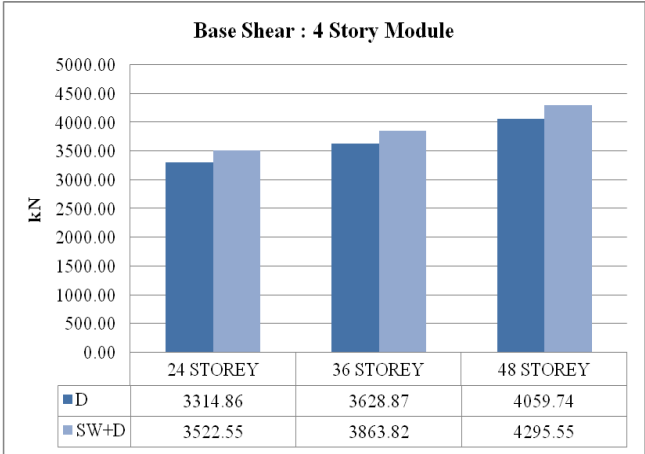


Fig. 20: Base shear 4 Story Module

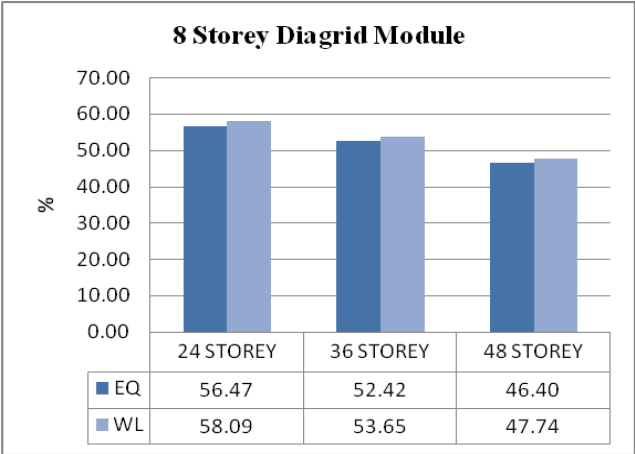


Fig. 18: 8 Story diagrid module

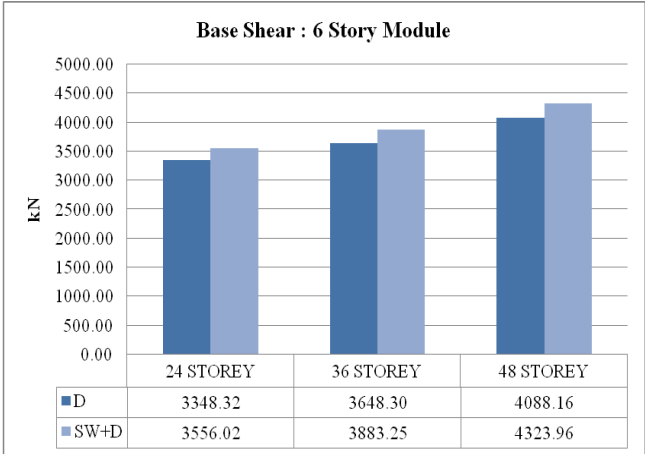


Fig. 21: Base shear 6 Story Module

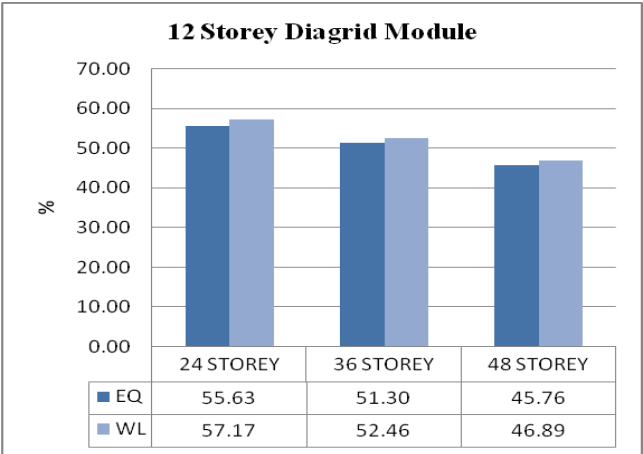


Fig. 19: 12 Story diagrid module

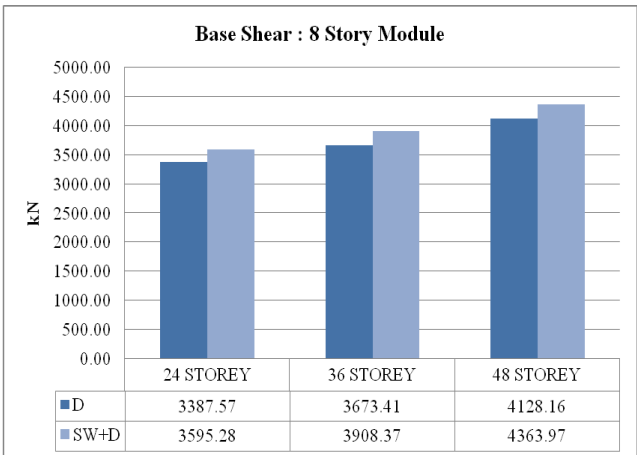


Fig. 22: Base shear 8 Story Module

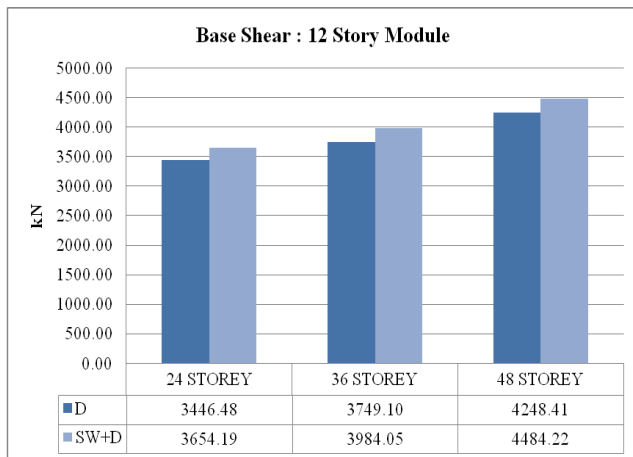


Fig. 23: Base shear 12 Story Module

#### 4.2.6 Percentage Increase In Quantity With Shear Wall

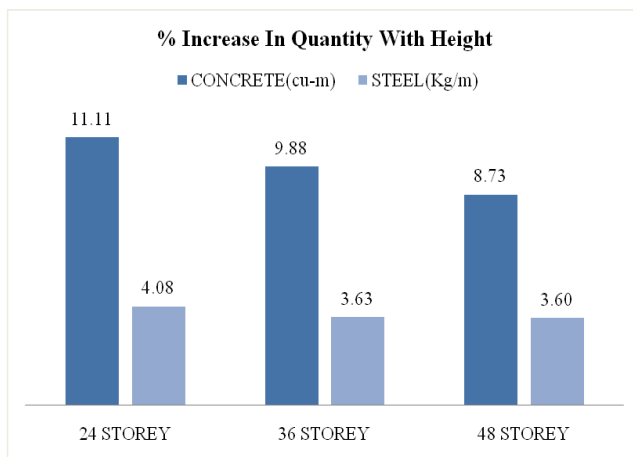


Fig. 24: % Increase In Quantity With Shear Wall

## V. CONCLUSION

In this paper a regular square plan of 30m × 30m diagrid structure considering different storey module (i.e. 4, 6, 8 & 12) with and without core Shear Walls is analysed and 24, 36 and 48 storey buildings are also considered. Parameters such as inter storey drift-ratio, storey displacement, base shear and reduction in lateral load on diagrid are taken into consideration.

- As results shows incorporation of shear walls at core of the diagrid structure is advantageous in many ways with very small increase in material quantity.
- By providing shear wall at core of diagrid structure maximum displacement reduced by 15-30% and maximum inter-storey drift ratio reduced by 15-50% (Higher decrement observed as the storey module increase) under both seismic and wind load.
- Shear walls almost eliminate the local stability issue and also eliminate the problem of large inter storey

drift within storey module, by increasing the stiffness of structure.

- Shear wall takes most of lateral loads and results in reduction in load on diagrid about almost half (45%-55%) compared to structure without shear wall.
- By incorporation of shear wall at core of diagrid structure, the increase in base shear is around 5 to 6% and material quantity is around 8-11% for concrete and 3-4% for steel which is considerably small.
- Further, shear wall takes 30% to 65% of lateral loads which reduces the lateral loads on diagrid at periphery which ultimately results in economical diagrid section compared to diagrid structure without shear walls at core.
- As per studies with increase in diagrid angle (higher storey module), material requirement for diagrid is less and for those structure inter storey module drift are large and stiffness reduced significantly therefore if shear wall is provided than large inter-storey drift and displacement are reduced and stiffness will increase.

## REFERENCES

- Elena Mele, Maurizio Toreno, Giuseppe Brandonisio And Antonello De Luca, "Diagrid Structures For Tall Buildings: Case Studies And Design Considerations", Struct. Design Tall Spec. Build. 23, 124–145 (2014), Wiley Online Library
- Kyoung Sun Moon, "Sustainable Structural Engineering Strategies For Tall Buildings", Struct. Design Tall Spec. Build. 17, 895–914 (2008), Wiley Interscience
- Valentina Tomeia, Maura Imbimbob, Elena Melec, "Optimization Of Structural Patterns For Tall Buildings: The Case Of Diagrid", Engineering Structures 171 (2018) 280–297, Elsevier Ltd.
- Mahdi Heshmatia, Alireza Khatamia, Hamzeh Shakiba, "Seismic Performance Assessment Of Tubular Diagrid Structures With Varying Angles In Tall Steel Buildings", Structures 25 (2020) 113–126, Elsevier Ltd.
- Neha Tirkey, G.B. Ramesh Kumar, "Analysis On The Diagrid Structure With The Conventional Building Frame Using ETABS", Materials Today: Proceedings, Elsevier Ltd.
- Jinkoo Kim And Young-Ho Lee, "Seismic Performance Evaluation Of Diagrid System Buildings", Struct. Design Tall Spec. Build. (2010), Wiley Online Library.
- Giovanni Maria Montuori, Elena Mele, Giuseppe Brandonisio, Antonello De Luca, "Secondary Bracing Systems For Diagrid Structures In Tall Buildings", Engineering Structures 75 (2014) 477–488, Elsevier Ltd.
- G. Lacidogna, D. Scaramozzino, A. Carpinteri, "Influence Of The Geometrical Shape On The Structural Behavior Of Diagrid Tall Buildings Under Lateral And Torque



- Actions”, *Developments In The Built Environment* 2 (2020) 100009, , Elsevier Ltd.
- [9] Giuseppe Lacidogna, Giuseppe Nittia, Domenico Scaramozzino, Alberto Carpinteria, “Diagrid Systems Coupled With Closed- And Open-Section Shear Walls: Optimization Of Geometrical Characteristics In Tall Buildings”, *Procedia Manufacturing* 44 (2020) 402–409, , Elsevier Ltd.
- [10] Khushbu D. Jani And Paresh V. Patel, “Design Of Diagrid Structural System For High Rise Steel Buildings As Per Indian Standards”, *Structures Congress 2013* © Asce 2013
- [11] Mir M. Ali and Kyoung Sun Moon, “Structural Developments in Tall Buildings: Current Trends and Future Prospects”, *Architectural Science Review* Volume 50.3, pp 205-223
- [12] Mustafa Küçük, Halil Ibrahim Arslan, “Investigation of Diagrid Structures Over Gherkin Tower”, *3rd International Conference of Contemporary Affairs in Architecture and Urbanism (ICCAUA-2020)* 6-8 May 202
- [13] Ahmad Rahimian, “Stability of Diagrid Structures”, *International Journal of High-Rise Buildings* December 2016, Vol 5, No 4, 263-270
- [14] “Design and Analysis of Tall and Complex Structures”, Feng Fu, ISBN: 978-0-08-101018-1